ANTIGENIC POLYPEPTIDE SEQUENCE OF FACTOR VIII, AND FRAGMENTS AND/OR EPITOPES OF THIS SEQUENCE.

Subject of the invention.

The present invention relates to the antigenic polypeptide sequence of factor VIII, to fragments and epitopes of this sequence and to the major parts of these epitopes, to the inhibitors which are directed against this sequence, its fragments, its epitopes and/or the major parts of these epitopes, and to the anti-inhibitors which are directed against the said inhibitors.

The present invention also relates to a pharmaceutical composition and to a diagnostic device comprising the abovementioned molecules.

Technical background underlying the invention.

Recently, factor VIII preparations which have been purified from large plasma pools by means of ion exchange chromatography, or very recently by means of immunoaffinity, have been made available to haemophilics in adequate quantities.

Various preparations of FVIII which have been obtained by genetic manipulation are currently under development or under clinical trial. These FVIIIs are either intact molecules or deleted molecules (Bihoreau (1992)).

FVIII is a glycoprotein cofactor of plasma coagulation and acts at the level of factor X (FX) activation. Characterization of FVIII and its mechanism of action is made more difficult because of its low concentration in the plasma, the size heterogeneity and its extreme sensitivity to enzymic degradation. This reaction comprises the proteolysis of FX to form activated factor X (FXa = Stuart factor) and brings into play a complex (Tenase complex) which comprises the enzyme (activated FIX or FIXa), a cofactor (activated FVIII or FVIIIa), calcium ions and phospholipids.

FVIII is a protein which is so complex that, even though the sequence of its gene has been known since 1984 (Verhar et al., Nature 312, pp. 317-342 (1984)), neither

the complete structure of plasma FVIII (only about 50% of the protein has been sequenced) nor the precise structure of the carbohydrates has yet been established. The DNA sequence has been allowed to define the primary sequence of FVIII (a rare exception to the instructions laid down by the FDA for therapeutic products derived from biotechnology).

Nevertheless, subtle differences between plasma FVIII and recombinant FVIII have been identified: i.e. glycosylation, plasma half-life following infusion, etc.

FVIII is in the main synthesized in the hepatocytes. It has been cloned in mammalian cells, insect cells and yeast cells (Webb et al., 1993). These glycoproteins which are produced by biotechnological processes can exhibit differences in the structure and composition of the sugars as compared with the natural protein. The cDNA of FVIII has also been expressed in transgenic sheep (Halter et al., 1993).

The cDNA encodes a polypeptide of 2351 amino acids, including the signal peptide of 19 amino acids which is cleaved off in the endoplasmic reticulum. Post-translational modifications take place in the Golgi apparatus: i.e. glycosylation of the serines and threonines and addition of sulphate ions to the tyrosine residues. Following maturation, the protein is subsequently secreted into the plasma in the form of 2 chains, of 210 kDa (up to residue 1648) and 80 kDa (from residue 1649 to residue 2332), which are joined by a divalent ion, with the lighter chain being linked non-covalently to the von Willebrand factor (vWf) by its N-terminal end (1 molecule of vWf per molecule of FVIII). In the plasma, this complex is stabilized by hydrophobic and hydrophilic bonds in the presence of a 50-fold excess of vWf. This latter is reported to inhibit the attachment of FVIII to phospholipids. The fact that FVIII binds to the platelets has been established, although the presence of specific receptors expressed on the surface of the platelets has not been clearly demonstrated (Nesheim et al., 1993). Following its attachment to the membrane

phospholipids, it is reported to unmask high-affinity binding sides for FIXa (Bardelle et al., 1993).

FVIII is made up of three structural domains, A, B and C (Kaufman RJ, 1992; Bihoreau et al., 1992) which are arranged in the order A1:A2:B:A3:C1:C2 (Figure 1). The A domains possess more than 40% homology and are also homologous to ceruloplasmin. 30% homology also exists between the A domains of factor V and FVIII. The C domain occurs twice and is reported to be able to bind glycoconjugates and phospholipids having a net negative charge (Kemball-Cook and Barrowcliffe (1992); Fay, PJ, 1993)). It exhibits homology with lectins which are able to bind to negatively charged phospholipids. The platelet attachment site has been located in this region (C2 domain) (Foster et al., (1990)). While domain B, which represents more than 40% of the mass of FVIII, does not have any known specific activity, it could play a subtle role in the regulation of FVIII by protecting it, for example, from the action of thrombin. It does not possess any known homology with other proteins.

It possesses 19 glycosylation sites out of the 25 which have been identified in FVIII. Comparison of the amino acid sequences of human and porcine FVIII reveals major differences within this B region. Nevertheless, porcine FVIII is used effectively for treating haemophilics exhibiting inhibitors. These observations have led to the construction of an FVIII gene from which the part encoding this B region has been deleted and which can be used to produce a deleted recombinant FVIII which is intended for the treatment of haemophilia.

Using immunopurification, different forms of active FVIII have been isolated which all possess a light chain of 80 kDa and whose heavy chain can have a molecular weight of between 210 and 90 kDa. These forms are reported to be derived by progressive degradation of the C-terminal end of the heavy chain. The binding of the two chains is non-covalent and results from a divalent metallic ion (Me++) bond between the responsible residues in domains A1 and A3. After formation of the activated

complex (50-45 kDa) (heavy chain having accessible A2 domain) and 70 kDa (light chain), an inactivation phase is observed, probably as a consequence of prolonged contact with thrombin and dissociation of the 50 kDa and 45 kDa fragments. FVIIIa is also inactivated by activated protein C (APC) following proteolysis of the heavy chain. This inactivation is accelerated if the FVIIIa is attached to a phospholipid surface. This down-regulation of the activity of FVIIIa is reported to depend on a phosphorylation by a platelet enzyme (Kalafatis et al., (1990)).

Most of the epitopes which are recognized by the various murine monoclonals which have been isolated to date do not appear to be located in the "functional sites" of FVIII. Some epitopes have been identified which are recognized by antibodies which have an effect on the activity of FVIII (inhibition of the chromogenic and/or clotting tests).

These antigenic determinants consist of fragments 351 - 365 (A1 domain - heavy chain), 713 - 740 (A2 domain), 1670 - 1684 (A3 domain - light chain) (NH_2 end of the light chain) or else 2303 - 2332 (C2 domain - light chain) (Foster C, (1990)), fragments 701 - 750 (Ware et al. (1989)), 1673 - 1689 (Leyte et al. (1989)), 330 - 472, 1694 - 1782 (EP-0 202 853), 322 - 740 and 2170 - 2322 (Scandella et al. (1992)).

The antibodies which recognize these various sites interfere, respectively, with the activation of FVIII, the binding of vWf or the binding of phospholipids.

Other antibodies, which do not inhibit standard activity tests in vitro, can exert an influence on the behaviour of FVIII with the other constituents of the coagulation cascade while attaching themselves to sites in the molecule which are at a substantial distance from the active sites. These antibodies, thus modified, can interfere with the natural state of folding of FVIII by altering some of its properties ("allosteric model").

These mapping experiments make use of peptides

which are synthesized by FVIII gene fragments which are cloned into E. coli and only provide an approximate idea of the location of the antigenic determinants which are recognized by these monoclonal antibodies. Thus, the sizes of the identified fragments range between 30 and 100 amino acids.

At present, it is necessary to crystallize a protein and analyse it with X rays in order to identify its antigenic sites unambiguously. Unfortunately, no data are available for FVIII, whose high molecular weight is a major handicap with regard to crystallization.

The antigenic regions coincide with the hydrophilic character of these regions: the more the oligopeptide sequence is exposed to the external medium (situated on the surface), the more this part is capable of being recognized in an immune reaction. By contrast, the hydrophobic parts, which are generally situated in the interior of the protein, are not considered to be very antigenic.

Currently, a predominant notion among haemophilic patients, clinicians and "fractionators" is that of having available a purified FVIII which is devoid of all pathogenic plasma contaminants and secondary effects.

However, whether after immunopurification using murine monoclonal antibodies or after obtaining it by genetic recombination in mammalian cells, highly purified FVIII is extremely unstable for reasons which are not apparent. In order to stabilize it, substantial quantities of human plasma albumin are added during the course of purification, such that the final specific activity is of the order of 2-3 U/mg of protein. The same applies to rFVIII which is coexpressed with the von Willebrand factor, which is a natural stabilizer, in CHO cells. These data appear to suggest that the purification steps exert an influence on the FVIII molecule, with these steps being able to interfere with its natural state of folding, to introduce confirmational changes which are more or less stable and to reveal new potential epitopes following infusion into the patient.

According to the authors (Ljung et al. (1992); Sultan et al., (1992); Lorenzo et al. (1992)), one of the serious complications which is seen in from 5 to 50% of the haemophilics who are given multiple therapeutic infusions of FVIII is the appearance of antibodies (inhibitors) which inactivate FVIII and render ineffective any subsequent injection of FVIII.

The spontaneous appearance of autoantibodies having a pathological anti-FVIII activity is rare in non-haemophilics (prevalence: 10^{-5}) and has been reported in elderly individuals, in those exhibiting immunological disorders and in post-partum individuals (Kessler (1991), Hultin (1991)). A multi-centre study which was carried out on 3,435 haemophilic patients shows that all the age groups are affected, including patients of less than 5 years old. The majority (82%) display a very high response (> 10 BU) (Sultan et al. (1992)). While these anti-FVIII antibodies have been reported to consist essentially of IgG antibodies of the IgG4 type, IgG2 (Gilles et al. (1993)b), IgA and IgM antibodies have also been described (Lottenburg et al. (1987)). They react weakly with purified heterologous FVIII molecules from other mammals (Bennett, B et al. (1972)). At the present time, it is not known what induces the appearance of the inhibitors in some haemophilics. If there is an association between the severity of the deletion of the gene and the development of an immune response which no longer recognizes FVIII as a self protein, this association is only demonstrated in a minority of patients. It has not been possible to demonstrate any specific host susceptibility which is linked to genetic markers, such as, for example, a preferential association with certain determinants of the MHC class II complex (Hoyer (1991)), without a doubt because not all the FVIII epitopes which are recognized by specific antibodies have yet been determined. It also appears that the different methods of preparing FVIII could exert an influence on its structure, its physicochemical properties or its natural microenvironment (Vermeylen, J and Peerlinck (1991);

Gomperts, et al. (1992); Peerlinck et al. (1993)). Barrowcliffe et al. (1983) have demonstrated that phospholipids protect the procoagulatory activity from inactivation by specific human antibodies. The presence of natural anti-FVIII antibodies in 17% of healthy donors (screening carried out on 500 plasma donations) without any pathological symptoms demonstrates the importance of becoming better acquainted with the three-dimensional structural appear-ance assumed by physiological FVIII (Ciavarella and Schiavoni (1992)).

Transfusion which has been studied on mixed lymphocyte cultures, in animal models and during clinical trials has demonstrated modification of the immuno-modulation in the transfused subject, inducing an allo-immunization and also a down-regulation of some immune functions. It expresses itself in the form of suppressor cells, anti-idiotype antibodies or a decrease in NK cells. It is as if a certain degree of tolerance was being induced. These effects can be reversed by infusing interleukin 2 (IL-2) (Triulzi et al., 1990). In vitro, an inhibitory effect on the secretion of IL-2 as well as the proliferation of peripheral blood mononuclear cells are obtained in the presence of a cryoprecipitate or relatively impure preparations of FVIII (from 0.5 to 10 U/mg of protein) (Madhok et al., 1991; Wadhwa, M et al., 1992). These effects are not observed in the presence of rFVIII or FVIII which have been purified by immuno-affinity. This latter preparation is reported to have an activating effect on T cells (Madhok et al., 1991). However, it is not possible to extrapolate these findings directly to an in vivo situation.

No experimental model exists which makes it possible to forecast the immunogenicity or the immuno-modulatory effect of the FVIII preparations, or the susceptibility of the host, before they have been administered clinically. This model becomes an absolute necessity in the face of the increase in the frequency of the appearance of anti-FVIII antibodies in current clinical trials which make use of FVIII preparation which

are of very high specific activity and which have been obtained either by immunopurification or by DNA manipulation techniques (Seremetis et al. (1991)). In addition, Aledorf (1993) has demonstrated that when these two types of preparation are used in naive subjects who have not previously been transfused (PUPS), an inhibitor prevalence is observed which amounts to up to 27%.

State of the art.

Patients who develop an anti-FVIII immune response find themselves in a serious situation which necessitates the use of severe, aggressive and excessively expensive measures. One of the most frequently employed techniques is to swamp the organism with regular injections of very high doses of FVIII (from 100 to 200 U/kg/day) (Ewing et al. (1988)) in association with a concentrated prothrombin complex (FEIBA) (Bonn's protocol), a procedure which effectively reduces the level of inhibitors in the blood (Sultan et al. 1986). In addition, this type of treatment has to be continued for a very long time (Lian et al., 1989). Trials carried out using smaller doses of FVIII have met with a certain degree of success in patients whose anti-FVIII antibody levels are much lower (Gruppo, (1991)).

An alternative approach is to use FVIII from a non-human species such as the pig, which FVIII is not neutralized by the anti-FVIII of the patient and enables haemostasis to take place. While a multi-centre study has shown the advantages of such a treatment, it has also demonstrated that anti-porcine FVIII antibodies are formed (Lozier (1993); Moreau et al. (1993); Hay and Bolton-Maggs (1991); Clyne et al. (1992)). Activated factor VIII, obtained by recombinant DNA technology, has also been employed as an alternative means for achieving coagulation in patients who exhibit inhibitors (Ingerslev et al. (1991)).

Recently, a profitable strategy (Nilsson et al. (1990)) for reducing the level of inhibitors has consisted in subjecting patients to an extracorporeal circulation to enable solid-phase absorption of the total IgG

to be effected on protein A while at the same time treating the patients with cytostatic agents such as cyclophosphamide.

The infusion of polyvalent intravenous immunoglobulins (IVIG), where appropriate combined with an immunosuppressive treatment, has been found to be relatively effective, although the reason for this effectiveness is still not fully established. Various hypotheses involving feed-back inhibition of IgG synthesis, stimulation of IgG clearance or activation of T suppressor cells have been advanced (Bloom (1992)). An interesting explanation is that these commercial intravenous immunoglobulins might contain antibodies which are able to react with the variable parts (idiotypes) of the anti-FVIII antibodies and neutralize these antibodies. It is suggested that this anti-idiotype activity might be specific to each donor and could be synergistic within an IgG pool (Dietrich et al. (1992)).

Unfortunately, none of these approaches has been found to be satisfactory in terms of safety, efficiency and cost.

Objects of the invention.

The present invention is aimed at obtaining an antigenic polypeptide sequence of factor VIII, and fragments and epitopes of this sequence, whose purpose is to improve the diagnosis and/or therapy of immune disorders, in particular those induced by inhibitors of FVIII and inhibitors of the binding of FVIII to the von Willebrand factor (vWf) and/or to membrane phospholipids (PL).

Another object of the invention is aimed at obtaining inhibitors which exhibit an immunoaffinity with this antigenic polypeptide sequence, its fragments and/or its epitopes, whose purpose is also to improve the diagnosis and/or therapy of immune disorders.

A supplementary object is aimed at obtaining anti-inhibitors, in particular antibodies, which are directed against the abovementioned said inhibitors and whose purpose is to improve the diagnosis and/or therapy

of immune disorders.

Brief description of the figures.

Figure 1 diagrammatically depicts the polypeptide sequence of factor VIII.

Figure 2 depicts the hydrophilicity graph of the A3 sequence of factor VIII renumbered from 1 to 371 amino acids (surface value for each amino acid).

Figure 3 depicts the flexibility graph for this A3 sequence of factor VIII.

Figure 4 depicts the accessibility graph for this A3 sequence of factor VIII.

Figure 5 depicts the general graph representing the sum of the values defined in Graphs 2 to 4.

Figure 6 depicts the demonstration of anti-factor VIII antibodies in mouse sera using an ELISA test.

Characteristic elements of the invention.

The present invention relates to the antigenic polypeptide sequence of factor VIII and/or fragments of this sequence, as described by Verhar et al. (Nature, Vol. 312, p. 339 (1984)).

The "polypeptide sequence of factor VIII" is understood to be the natural human or animal sequence, which may be glycosylated and which has been obtained by purification from pools of plasma, in particular Cohn fraction I, by synthesis and/or by genetic manipulation (that is including a sequence from which portions which are not involved in the mechanism of blood coagulation may have been deleted) of factor VIII.

The present invention relates, in particular, to the antigenic polypeptide sequence of factor VIII which lacks fragments alanine 322 - serine 750, leucine 1655 - arginine 1689, lysine 1694 - proline 1782 and aspartic acid 2170 - tyrosine 2332.

The present invention relates, in particular, to the antigenic polypeptide sequences A1, A2, A3 and C (C1 and C2) of factor VIII.

In the remainder of the text, the amino acids will be represented by their three-letter abbreviations

or by the single-letter symbol, as identified in the table below.

Alanine	Ala	A	Leucine	Leu	L
Arginine	Arg	R	Lysine	Lys	K
Asparagine	Asn	N	Methionine	Met	M
Aspartic acid	Asp	D	Phenylalanine	Phe	F
Cysteine	Cys	C	Proline	Pro	P
Glutamine	Gln	Q	Serine	Ser	S
Glutamic acid	Glu	E	Threonine	Thr	T
Glycine	Gly	G	Tryptophan	Trp	W
Histidine	His	H	Tyrosine	Tyr	Y
Isoleucine	Ile	I	Valine	Val	V

A first embodiment of the invention relates to the antigenic polypeptide sequence A3 of factor VIII, and to fragments and/or epitopes of this sequence. The said sequence is contained between glutamic acid 1649 and asparagine 2019, preferably between arginine 1652 and arginine 1917 or between arginine 1803 and arginine 1917, of the polypeptide sequence of factor VIII as published by Verhar et al. (Nature, vol. 312, p 339 (1984)) and Toole et al. (Nature, vol. 312, pp. 342-347 (1984)).

Preferably, the fragments of the said sequence are contained between arginine 1652 and arginine 1696, preferably between arginine 1652 and arginine 1689, between threonine 1739 and aspartic acid 1831 or between glutamic acid 1885 and arginine 1917.

The invention also relates to the sequence epitopes of these fragments, in particular:

- the epitope contained between arginine 1652 and tyrosine 1664, defined by the following sequence:

SEQ ID No:1:

Arg Thr Thr Leu Gln Ser Asp Gln Glu Glu Ile Asp Tyr
1 5 10

- the epitope contained between aspartic acid 1681 and arginine 1696, defined by the following sequence:

SEQ ID No:2:

Asp Glu Asp Glu Asn Gln Ser Pro Arg Ser Phe Gln Lys Lys Thr Arg
1 5 10 15

- the epitope contained between threonine 1739 and tyrosine 1748, defined by the following sequence:

SEQ ID No:3:

Thr Asp Gly Ser Phe Thr Gln Pro Leu Tyr
1 5 10

- the epitope contained between asparagine 1777 and phenylalanine 1785, defined by the following sequence:

SEQ ID No:4:

Asn Gln Ala Ser Arg Pro Tyr Ser Phe
1 5

- the epitope contained between glutamic acid 1794 and tyrosine 1815, defined by the following sequence:

SEQ ID No:5:

Glu Asp Gln Arg Gln Gly Ala Glu Pro Arg Lys Asn Phe Val Lys Pro
1 5 10 15
Asn Glu Thr Lys Thr Tyr
20

- the epitope contained between methionine 1823 and aspartic acid 1831, defined by the following sequence:

SEQ ID No:6:

Met Ala Pro Thr Lys Asp Glu Phe Asp
1 5

- the epitope contained between glutamic acid 1885 and phenylalanine 1891, defined by the following sequence:

SEQ ID No:7:

Glu Thr Lys Ser Trp Tyr Phe
1 5

- the epitope contained between glutamic acid 1893 and alanine 1901, defined by the following sequence:

SEQ ID No:8:

Glu Asn Met Glu Arg Asn Cys Arg Ala
1 5

- the epitope contained between aspartic acid 1909 and arginine 1917, defined by the following sequence:

SEQ ID No:9:

Asp Pro Thr Phe Lys Glu Asn Tyr Arg
1 5

Advantageously, the said sequence, its specific fragments and its epitopes exhibit an antigenic characteristic which is illustrated by appended figures 2 to 5.

Another preferred embodiment of the invention relates to antigenic polypeptide sequence A1 of factor VIII and fragments and/or epitopes of this sequence.

Preferably, the fragments of the said sequence are contained between alanine 108 and methionine 355, preferably between alanine 108 and glutamine 228.

The invention also relates to the sequence epitopes of these fragments, in particular:

- the epitope contained between alanine 108 and valine 128, defined by the following sequence:

SEQ ID No:10:

Ala Ser Glu Gly Ala Glu Tyr Asp Asp Gln Thr Ser Gln Arg Glu Lys
1 5 10 15
Glu Asp Asp Lys Val
20

- the epitope contained between glutamic acid 181 and leucine 192, defined by the following sequence:

SEQ ID No:11:

Glu Gly Ser Leu Ala Lys Glu Lys Thr Gln Thr Leu
1 5 10

- the epitope contained between aspartic acid 203 and glutamine 218, defined by the following sequence:

SEQ ID No:12:

Asp Glu Gly Lys Ser Trp His Ser Glu Thr Lys Asn Ser Leu Met Gln
1 5 10 15

- the epitope contained between aspartic acid 327 and methionine 355, defined by the following sequence:

SEQ ID No:13:

Asp Ser Cys Pro Glu Glu Pro Gln Leu Arg Met Lys Asn Asn Glu Glu
1 5 10 15
Ala Glu Asp Tyr Asp Asp Asp Leu Thr Asp Ser Glu Met
20 25

Another preferred embodiment of the invention relates to the antigenic polypeptide sequence A2 of factor VIII and fragments and/or epitopes of this sequence.

Preferably, the fragments of the said sequence are contained between aspartic acid 403 and aspartic acid 725, preferably between histidine 693 and aspartic acid 725.

The invention also relates to the sequence epitopes of these fragments, in particular:

- the epitope contained between aspartic acid 403 and lysine 425, defined by the following sequence:

SEQ ID No:14:

Asp Asp Arg Ser Tyr Lys Ser Gln Tyr Leu Asn Asn Gly Pro Gln Arg
1 5 10 15
Ile Gly Arg Lys Tyr Lys Lys
20

- the epitope contained between valine 517 and arginine 527, defined by the following sequence:

SEQ ID No:15:

Val Glu Asp Gly Pro Thr Lys Ser Asp Pro Arg
1 5 10

- the epitope contained between histidine 693 and glycine 701, defined by the following sequence:

SEQ ID No:16:

His Asn Ser Asp Phe Arg Asn Arg Gly
1 5

- the epitope contained between serine 710 and aspartic acid 725, defined by the following sequence:

SEQ ID No:17:

Ser Cys Asp Lys Asn Thr Gly Asp Tyr Try Gly Asp Ser Tyr Glu Asp
1 5 10 15

A final preferred embodiment of the invention relates to the antigenic polypeptide sequence C of factor VIII, and fragments and/or epitopes of this sequence. Preferably, the fragments of the said sequence are contained between lysine 2085 and lysine 2249, preferably between lysine 2085 and glycine 2121.

The invention also relates to the sequence epitopes of these fragments, in particular:

- the epitope contained between lysine 2085 and phenylalanine 2093, defined by the following sequence:

SEQ ID No:18:

Lys Thr Gln Gly Ala Arg Gln Lys Phe
1 5

- the epitope contained between aspartic acid 2018 and glycine 2121, defined by the following sequence:

SEQ ID No:19:

Asp Gly Lys Lys Trp Gln Thr Tyr Arg Gly Asn Ser Thr Gly
1 5 10

- the epitope contained between glycine 2242 and lysine 2249, defined by the following sequence:

SEQ ID No:20:

Gly Val Thr Thr Gln Gly Val Lys
1 5

The invention also relates to the major parts of the said epitopes or the said fragments, that is to say to the portions of the sequences of the said epitopes which contain the amino acids tyrosine and histidine, which unexpectedly display a particularly high affinity towards inhibitors of factor VIII. Preferably, these major parts contain the said amino acid tyrosine or histidine linked to at least two other identical or different amino acids.

These sequences, these fragments and these epitopes, in particular the major parts of the epitopes or the fragments, are particularly advantageously characterized by high hydrophilicity, such as described by Parker, Guo and Hodges (Biochemistry 25, pp 5425-5432 (1986)), considerable flexibility, such as described by Karplus and Schultz (Naturwissenschaften 72, p 212 (1985)) and considerable accessibility, such as described by Janin (Nature 277, pp 491-492 (1979)) (see Figures 2 to 5).

These fragments and these epitopes are, in particular, exposed on the surface of the factor VIII protein and exhibit a pronounced antigenic characteristic.

Advantageously, the said polypeptide sequence, its fragments, its epitopes and/or these major parts of the said fragments or the said epitopes are also independently immunogenic (that is to say they are immunogenic even without being complexed with a protein of large size such as BSA, haemocyanin, etc.), and preferably exhibit an immunoaffinity within inhibitors of factor VIII, such as anti-factor VIII antibodies, and/or exhibit an immunoaffinity for the receptors of the T lymphocytes and/or B lymphocytes.

This sequence, these fragments, these epitopes and/or the major parts of the said fragments or the said epitopes induce an immune reaction (antibody synthesis) when they are injected into a rabbit.

These characteristics are particularly pronounced in the case of the epitopes SEQ ID No:2 and SEP ID NO:5, which comprise sequences which are relatively "long" in amino acids, i.e. comprise 16 and 22 amino acids, respectively.

These sequences are therefore characterized by substantial immunogenicity towards monoclonal and polyclonal antibodies.

However, these sequences are sufficiently short to be readily obtained by synthesis.

As an example, peptides Asp 1681 - Arg 1696 and Asp 327 - Met 355 were synthesized in order to demonstrate the presence of anti-factor VIII antibodies in mouse sera using an ELISA test.

The free peptides (not coupled to a carrier protein) were injected into two BALB/C mice in accordance with the following protocol:

- day 0 100 µg of peptide emulsified in incomplete Freund's adjuvant are injected intramuscularly.
- days 7, 14, 21 and 28:
  immunization with 50 µg of peptide.

A sample of blood is withdrawn on each day before the injection. Polystyrene microtitration plates (NUNC) are saturated with a preparation of plasma factor which is diluted with the aid of 40 IU/ml. 50 µl volumes of

increasing dilutions (1/60, 1/300 and 1/600) of mouse antisera are added to the wells. Following incubation and washing, the presence of anti-factor VIII antibodies is demonstrated by adding 50 µl of a 1/5000 dilution of a rabbit anti-mouse IgG antibody which is labelled with biotin. Following incubation and washing, the wells are incubated with 50 µl of avidin/peroxidase (1/2500) and washed, with 100 µl of OPD finally being added to the wells. The optical density is measured at 490 nm. The results of the ELISA are presented in appended Figure 6 (EX1, EX2 and a sample, termed BLC, which serves as the blank).

The present invention also relates to the conformational epitopes which comprise at least two different fragments of the said sequence, at least two sequence epitopes and/or at least two major parts of the said epitopes or the said different fragments according to the invention and identified above.

The conformational epitopes are made up of two or more different portions of a polypeptide sequence, which portions are located in proximity to each other when the protein is folded in its tertiary or quaternary structure.

These epitopes are capable of being "recognized" (that is to say of exhibiting an immunoaffinity), preferably simultaneously, with inhibitors of factor VIII, in particular B lymphocytes (by way of the major histocompatibility locus (MHC I and/or II)) and/or anti-factor VIII antibodies (Scandella et al., Blood 76, p 437 (1990)).

Preferably, the said sequence, the said fragments, the said epitopes and/or the major parts of the said epitopes or the said fragments are complexed with a carrier protein or a carrier peptide, such as BSA or haemocyanin, in such a way as to form a complex exhibiting a more powerful immunogenicity.

Another aspect of the present invention relates to an inhibitor of factor VIII which exhibits an immunoaffinity with the antigenic polypeptide sequence accord-

ing to the present invention, with fragments and epitopes of this sequence, with major parts of the said epitopes or the said fragments and/or with the complex according to the invention.

An inhibitor is understood to mean any biological molecule or cell which intervenes with and/or against factor VIII and is capable of giving rise to immune disorders.

In particular, such an inhibitor can be an anti-factor VIII monoclonal or polyclonal antibody (gamma-globulin) or antibody fragment (such as the hypervariable Fab portion of the said antibody) which inactivates the said factor VIII and/or which inhibits the binding of factor VIII to the von Willebrand factor and/or to membrane phospholipids.

Advantageously, the said inhibitors are synthesized by a "chimaeric" animal which comprises a human immune system, such as an hu-SCID mouse producing human antibodies.

SCID (severe combined immunodeficient) mice are mice which exhibit a deficiency in functional B and T lymphocytes due to dysfunction of the recombination of the genes which are responsible for the antigenic receptors. The immune system of the SCID mice can be reconstituted using immunocompetent cells of human origin which are derived from foetal organs or peripheral blood (Mosler et al. (1988)).

Once reconstituted, these hu-SCID mice produce human antibodies either spontaneously or after immunization.

There does not appear to be any dramatic cross reactivity between human factor VIII and murine factor VIII (Kessler, 1991).

The peripheral blood lymphocytes are taken from several types of donor: non-haemophilic volunteers, haemophilics who lack inhibitors which can be detected by standard methods, haemophilics who exhibit substantial inhibitor levels and donors who are producing autoantibodies.

This model is employed in two types of study. Firstly, the mice are reconstituted with cells from a single donor, and it is possible to compare the antigenicity of several factor VIII preparations once the reproducibility of the system has been verified.

On the other hand, it is possible, using this model, to obtain and study an anti-factor VIII response at the clonal level.

Study of the specific monoclonal response of the B cells is very important since this enables the sequential and conformational epitopes of factor VIII to be identified precisely. The B cells are cultured, cloned in the presence or absence of anti-CD40 antibodies, from the spleens of mice which are producing anti-factor VIII antibodies, or else transformed in the presence of EBV virus. The anti-CD40 antibodies recognize a membrane antigen and activate the B cells in the presence of a fibroblast line (Banchereau et al. 1991)). It is consequently possible to envisage using these immunodominant epitopes as a possible target for immunotherapy.

Determination of the MHC class I and class II markers which are carried by the B lymphocyte clones makes it possible to analyze the immune response of the anti-factor VIII antibodies at the genetic level and thereby to follow recognition by the specific T cells. This is also an excellent method for seeing whether there is a risk factor associated with this pathology.

The BALB/C mice which are selected for preparing the anti-factor VIII Mabs are firstly injected on three occasions, at 2 week intervals, with a solution of recombinant factor VIII (rFVIII). This type of preparation has the advantage of containing a high-purity factor VIII at elevated concentration together with a minimum of contaminating proteins. Four days after the last injection, the splenocytes are fused with the cells from a mouse myeloma (SP207) (van Snick and Coulie (1982)). The hybridomas which are producing anti-factor VIII antibodies are selected by the ELISA technique, using polystyrene plates on which rFVIII has previously been

insolubilized. The hybridoma supernatants containing the anti-factor VIII antibodies are cloned by the limiting dilution technique and then cultured in vitro.

The antibodies are purified from these supernatants by means of chromatography.

The ELISA technique is used to quantify, and to determine the light chain (k or l) and the subclass (IgG1, IgG2a, IgG2b or IgG3) of the anti-factor VIII Mabs.

The epitopes which are recognized on the factor VIII molecule are determined by means of the immunotransfer technique using solutions of native factor VIII or factor VIII which has been cleaved enzymically with thrombin.

The ability of each of the anti-factor VIII Mabs which have been produced to inhibit function is evaluated both by a coagulation method (Bethesda method) (Kasper et al. (1975)) and by a chromogenic method which is based on the ability which is possessed by factor X, which has been activated by association with factor VIII and activated factor IX, to transform a colourless substrate into a coloured substrate (Svendsen et al. (1984)).

The cell lines which produce human monoclonal anti-factor VIII antibodies are derived from human B lymphocytes which are taken from the abdominal cavity of SCID mice which have been immunized with different batches of factor VIII after reconstitution of the immune system of the animals with human lymphocytes. The B lymphocytes are cultured in the presence of fibroblast cells which express a receptor for the immunoglobulin Fc moiety, to which is attached a monoclonal anti-CD40 antibody. These cells, which have been activated by polymerization of the CD40 receptor, are then infected and immortalized with Epstein-Barr virus (Kozbor, (1981)). The cell lines which produce the sought-after antibodies can then be subcloned.

Another aspect of the invention relates to an anti-inhibitor which is characterized in that it is directed against the said previously described factor

VIII inhibitor.

An anti-inhibitor which is directed against the factor VIII inhibitor is understood to mean any biological molecule and/or cell which is capable of interfering with the said inhibitor in such a way as to ensure its inactivation.

Preferably, such an anti-inhibitor is an anti-anti-factor VIII idiotype (monoclonal or polyclonal) antibody or antibody fragment.

Advantageously, these anti-inhibitors which are directed against the factor VIII inhibitors are synthesized by a "chimaeric" animal exhibiting a human immune system, such as an hu-SCID mouse.

Only mice which produce less than 10 μg/ml residual immunoglobulins are used for the experiments.

The model is developed using peripheral leucocytes which are derived from volunteers who have been immunized against tetanus.

The reconstitution is effected by means of a single i.p. injection of from 15 to 20.10^6 mononuclear cells of human origin. These cells are obtained after centrifuging peripheral blood (approximately 200 ml) on a Ficoll/Hypaque gradient. From twelve to twenty mice can be reconstituted from one single donor. The production of human immunoglobulins is measured as a function of time.

The anti-anti-factor VIII idiotype antibodies are purified from a pool of starting plasma which is assembled from voluntary donations from at least 7200 donors in order to increase the probability of finding anti-idiotype antibodies by means of immunoaffinity using human anti-factor VIII antibodies which are covalently attached to a Sepharose column or attached by means of an Fc moiety to a protein G column. Following fractionation, by means of the Cohn-Oncley method, two IgG-rich fractions, Fr II and Fr III, are obtained. They will serve as the starting preparation for purifying the anti-idiotype antibodies. These monoclonal antibodies will be obtained from B cells which have been taken from haemophilic patients. These cells have initially prolif-

erated in SCID mice and have been transformed into secretory cell cultures by the EBV virus. Use of these human monoclonal antibodies makes it possible to avoid introducing non-human proteins into the therapeutic preparations. These preparations are evaluated, by means of detailed immunochemical analysis, for their efficiency in neutralizing the inhibitors which are derived from the largest possible number of haemophilic patients. Several physical (treatment with UVCF radiation), thermal and/or chemical (for example using a solvent/detergent) viral inactivation steps are introduced into the purification process in order to ensure the greatest possible degree of viral safety.

The idiotype which is peculiar to the human antibodies is analyzed by sequencing the variable moiety of the molecule. These data are of the utmost importance because they are of great value both in diagnosing and regulating the production of anti-factor VIII antibodies.

Up to the present time, the source of the antibodies which are required for preparing antigen/antibody complexes has been autologous, that is to say the patient himself was supplying the antibodies. It has recently become clear that normal individuals, having normal levels of circulating factor VIII, produce anti-factor VIII antibodies whose activity in the plasma is limited by corresponding anti-idiotype antibodies. Anti-factor VIII antibodies which have been prepared from a gammaglobulin pool can advantageously replace the autologous source.

It is also possible to obtain human B cells which have been transformed with the EBV virus and which produce inhibitors from haemophilic or non-haemophilic patients. Four lines have thus been obtained, with one of these lines recognizing the light chain of factor VIII. SCID mice have been repopulated with inhibitor-secreting B cells derived from haemophilic or non-haemophilic patients. Production is stimulated by injecting plasma factor VIII and recombinant factor VIII. It is therefore possible to obtain continuous in-vitro cultures which are

producing the said inhibitors. Anti-anti-factor VIII idiotype antibodies can also be produced continuously using this technique.

Another aspect of the invention relates to a pharmaceutical composition which comprises an element which is selected from the group consisting of the said antigenic polypeptide sequence of factor VIII, fragments and epitopes of this sequence and/or major parts of the said epitopes or the said fragments, an inhibitor of factor VIII which is directed against them, an anti-inhibitor which is directed against the said inhibitor, and/or a mixture of these.

Another aspect of the invention relates to a diagnostic and/or purification device such as a diagnostic kit or a chromatography column (such as described by Ezzedine et al. (1993)), which comprises an element which is selected from the group consisting of the antigenic polypeptide sequence according to the invention, fragments and epitopes of this sequence and/or the major parts of the said epitopes or the said fragments, the complex according to the invention, an inhibitor which is directed against them, an anti-inhibitor which is directed against the said inhibitor, and/or a mixture of these.

The purification device can therefore consist of a chromatography column such as described by Ezzedine et al. (1993) which comprises the sequence of factor VIII, fragments and epitopes of this sequence and/or the major parts of the said fragments or epitopes, which are attached to the solid phase of the chromatography column.

A physiological liquid (such as serum), which is derived from a patient and which comprises inhibitors of factor VIII, is then caused to pass through this chromatography column, with the said inhibitors (for example antibodies) becoming attached specifically to the said factor VIII, the said fragments, the said epitopes or the said major parts.

Following elution, it is possible to collect the said inhibitors by causing them to react with anti-

inhibitors (anti-anti-factor VIII idiotype antibodies).

It is also possible to characterize the anti-anti-factor VIII idiotype antibodies which are present in a serum by causing these anti-inhibitors to be passed through a chromatography column on which inhibitors of factor VIII have been attached to the solid phase.

A final aspect of the invention relates to the use of the pharmaceutical composition according to the invention for preparing a medicament to be used for preventing and/or treating immune disorders, in particular those which are induced by inhibitors of factor VIII, inhibitors of the binding of factor VIII and the von Willebrand factor (vWF) and/or inhibitors of the binding of factor VIII to membrane phospholipids.

References.

- Aledort, L.M. (1993), Sem Hematol 30, 7-9
- Bardelle, C., Furie, B., Furie, B.C. and Gilbert, G.E. (1993), J. Biol. Chem. 268, 8815-8824
- Barrowcliffe, T.W. (1993), Sem Thromb Hemost 19, 73-79
- Bennet, B., Ratnoff, O.D. (1972), Procédé Sol Exp Biol Med 143, 137-155
- Bihoreau, N. (1992), M/S 8, 1043-1050
- Blomm, A.L. (1992), Haemost 22, 268-275
- Blanchereau, J., de Paoli, P., Vallé, A., Garcia, E. and Rousset, F. (1991), Science 251, 70
- Cauldfield, M.J. and Schaffer, D. (1987), J. Immunol 138, 3680
- Ciavarella, N. and Shiavoni, M. (1992), Lancet 339, 1301
- Clyne, L.P., Levy, A., Stein and McPhedran, P. (1992), Thromb and Haemost 68, 475-476
- Dietrich, G., Algiman, M., Sultan, Y., Nydegger, U.E., Kazatchkine, M.D. (1992), Blood 79, 2946-2951
- Ehrenforth, S., Kreuz, W., Scharrer, I., Linde, R., Funk, M., Gungor, T., Krackhardt, B. and Kornhuber, B. (1992), Lancet 339, 594-598
- Elder, B., Lakich, D. and Gitschier, J. (1993), Genomics 16, 374-379
- Ewing, N.P., Sanders, N.L., Dietrich, S.L. and Kasper, C.K. (1988), JAMA 259, 65-68
- Fay, P.J. (1993), Thromb Haemost 70, 63-67
- Fulcher, C.A., Roberts, I.Z., Holland, Tous and Zimmerman, Tous (1985), J. Clin Invest 76, 1117-1124
- Foster, P.A., Fulcher, C.A., Houghten, R.A. and Zimmerman, T.S. (1985), Blood 75, 1999-2004
- Gilles, J.G., Armout, J. Vermylen, J and Saint-Rémy, J.M. (1991), XIVth Int Congress Allerg and Clin Immunol October 13-18
- Gilles, J.G. and Saint-Rémy, J.M. (1993a), XIVth Congress Int Soc Thromb Haemost July 49
- Gomperts, E.D., de Biasi, R. and De Vreker, R. (1992), Transfusion Med Rev 1, 44-54

- Gruppo, R. (1991), Thromb Haemostas 65, 1168
- Halter, R., Carnwath, J., Espanon, G., Herrman, D., Lemme, E., Niemenn, H. and Paul, D. (1993), Theriogenology 39, 137-149
- Hay, C.R.M. and Bolton-Maggs (1991), Transfusion Med Rev V, 145-151
- Hedner, U. and Tenborn (1985), Thromb Haemostas 54, 776-779
- Hultin, M.B. (1991), Am J. Med. 91 (Suppl 5A), 23-27
- Hoyer, L.W. (1991), Am J. Med. 91 (Suppl 5A), 405-409
- Ingerslev, J., Feldstedt, M. and Sindet-Pedersen (1991), Lancet 338, 831-832
- Kalafatis, M., Rand, M.D., Jenny, R.J., Erlich, Y.H. and Mann, K.G. (1993), Blood 81, 704-709
- Kaufman, Rj. (1992), Transfusion Med Rev VI, 235-246
- Kasper, C.K., Aledort, L.M., Edson, J.R., Fratantone, J., Green, D. et al. (1975), Thrombos Diathes Haemorh 34, 869
- Kemball-Cook, G. and Barrowcliffe, T.W. (1992), Thromb Res 67, 57-71
- Kessler, C.M. (1991), Am. J. Med. 91 (Suppl. 5A), 15-19
- Kosbor, D. and Roder, J.C. (1981), 127-1275
- Leroy, B.L., Lachapelle, J.M., Jacquemin, M.G. and Saint-Rémy, J.M.R. (1992), Dermatology 184:271
- Leyte et al. (1989), Biochem J. 263, 189-194
- Lian, E.C.Y., Larcada, A.F. and Chiu, A.Z.Y. (1989), Ann Int Med 110, 771-778
- Ljung, R., Petrini, P., Lindgren, A.C., Tengborn, L. and Nilsson, I.M. (1992), Lancet 339, 1550
- Lorenzo, J.L., Garcia, R. and Molina, R. (1992), Lancet 339, 1551
- Lottenburg, R. Kentro, T.B. and Kitchins, C.S. (1987), 147, 1077-1081
- Lozier, J.N., Santagostino, E., Kasper, Ck., Teitel, J.M. and Hay, C.R.M. (1993), Sem Hematol 30, 10-21
- Madhok, R., Smith, J., Jenkind, A. and Lowe, G.D.O. (1991), Br. J. Haematol 79, 235-238

- Mc Cune, L.M., Namikawe, R., Kaneshima, H., Schultz, L.D., Lieberman, M. and Weissman, I.L. (1988), Sciences 241, 1632-1639
- Moreau, P.H., Staikowsky, F., Laneelle, D., Dellile, F., Simonin, D., Schiffer, C. and Laurian, Y. (1993), Presse Méd 22, 472-479
- Mosler, D.E., Gulizia, R.J., Baird, S.B. and Wilson, D.B. (1988), Nature 335, 256-259
- Nesheim, M.E. Furmaniak-Kazmierczak, E., Henin, C.H. and Côté, G. (1993), Thromb and Haemost 70, 80-86
- Nilsson, J.M., Berntop, E., Zettervall, O. and Dahlbäck, B. (1990), Blood 10, 378-383
- Peerlinck, K., Arnout, J., Tamise, A., Vanherle, P., Fondu, P. and Vermylen, J. (1991), Acta Clin Belg 46, 298-304
- Peerlinck, K., Arnout, J., Gilles, J.G., Saint-Rémy, J.M. and Vermylen, J. (1993a), Thromb Haemost 69, 2, 115-118
- Peerlinck, K., Rosendaal, F.R. and Vermylen, J. (1993a), Blood 81, 3332-3335
- Scandella, D., de Graaf Mahoney, S., Mattingly, M., Roeder, D., Timmons, L. and Fulcher, C.A. (1985), Proc. Natl. Acad. Sci. USA 85, 6152-6156
- Scandella, D., Timmons, L., Mattingly, M., Trabold, N. and Hoyer, L.W. (1992), Thromb Haemost 65, 1160
- Seremitis, S., Aledort, L., Lusher, M., Hilgartner, M., Mannucci, P.M. and Mariani, G. (1991), Thromb Haemostas 65, 1160
- Smith, C.I.E., Habedi, M., Islam, K.B., Johansson, M.E.B., Christenson, B. and Hammerström, L. (1991), Immunol Rev 124, 113-135
- Sultan, Y., Rossi, F. and Kazatchkine, M. (1987), Proc. Natl. Acad. Sci. 84, 828-831
- Sultan, Y., White, G.C., Aronstam, A., Bosser, C., Brackmann, H.H. et al. (1986), Nouv Rev Fr Hematol 28, 85-89
- Sultan, Y. and French Hemophilia Study Group (1992), Thromb Haemost 67, 600-602
- Svendsen, L., Brogli, M., Lindeberg, G. and Stocker,

K. (1984), Thrombos Res 34, 457

- Triulzi, D.J., Heal, J.M. and Blumberg, N. (1990), In "Transfusion Medicine in the 1990s", Ed. Nance, S.T.; American Association of Blood Banks; Arlington, Virginia
- Van Snick, J. and Coulie, P. (1982), J. Exp Med 155, 219
- Vermylen, J. and Peerlinck, K. (1991), Acta Clin Belg 46, 419-420
- Wadhwa, M., Dilger, P., Tubbs, J., Barrowcliffe, T., Mahon, B. and Thorpe, R. (1992), Br. J. Haematol 82, 578-583
- Ware, J., MacDonald, M.J., Lo, M., de Graaf, S. and Fulcher, C.A. (1992), Blood Coagul Fibrin 3, 703-716
- Webb, E., Tkalcevic, S., Hocking, D. and Nisbet, I. (1993), Biochem Biophys Res Commun 190, 536-543